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TRACKING A LASER-PROJECTED HORIZON INDICATOR: SOME FURTHER DEVELOPMENTS

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Spatial disorientation or the loss of situational awareness has been identified as the primary or secondary cause of 15-25% of all fatal military aircraft accidents. One of the promising recent attempts to combat disorientation has focused on the peripheral vision horizon device (PVHD).

The current set of experiments indicate that when two fixed-length PVHD horizon line segments (straight line with missing central segment) are progressively moved outward, away from central vision, the ability to track the horizon does not improve but diminishes. Tracking performance was not optimal when the horizon line segments were presented to retinal areas having the highest visual rod density as speculated in our initial report. Improvements in compensatory tracking with PVHD presentations appear to be related to absolute size of the horizon (Bigger is Better).

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SUMMARY PAGE

THE PROBLEM

Spatial disorientation or the loss of situational awareness has been identified as the primary or secondary cause of 15-25% of all fatal military aircraft accidents (1,2). One of the most promising recent attempts to combat disorientation has focused on the Peripheral Vision Horizon Device (PVHD). The two experiments reported herein complete our initial phase of experimentation designed to investigate the physiological mechanisms on which the PVHD is based.

FINDINGS

The current set of experiments indicate that when two fixed-length PVHD horizon line segments (straight line with missing central segment) are progressively moved outward, away from central vision, the ability to track the horizon does not improve and, in fact, diminishes. Tracking performance was not optimal when the horizon line segments were presented to retinal areas having the highest visual rod density as we speculated in our initial report. Improvements in compensatory tracking with PVHD presentations appear to be related to absolute size of the horizon.

RECOMMENDATIONS

In planning PVHD implementation for operational aircraft, design specialists should maximize the size of the horizon presentation ("bigger is better").

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INTRODUCTION

This report completes our initial experimentation on the physiological mechanisms of wide visual-angle, laser-projected, artificial horizons, which have been called Peripheral Vision Horizon Devices (PVHD) or the "Malcolm Horizon." When used in an aircraft, the PVHD projects an artificial horizon across the cockpit instrument panel. This is thought to allow the pilot to use peripheral vision to monitor aircraft attitude while simultaneously using foveal vision to process other information--a classic example of parallel perceptual processing (3). Another proposal is that presenting attitude information via the peripheral retina takes advantage of a "natural" information channel designed for relative motion detection versus acuity discrimination (4,5). An example of this application is the ability to read a book while walking along a corridor without bumping into the walls.

Our initial report (6) indicated that larger artificial horizons were tracked with less error than shorter horizons. A 10^{o} roll deflection of a very short line (< 3-4^{o} visual angle) is more difficult to detect and correct than the same 10^{o} deflection of a very long line (e.g., 90^{o}). If one attends to the extreme end of the horizon line, the absolute movement (vertical displacement) of the end of the line is much greater with the long horizon. The larger the absolute displacement (movement of the stimulus across the retina) of the line, the more visual rods should be stimulated and the detection threshold should correspondingly be improved.

The primary goal of these experiments was to determine which part of the peripheral retinal field contributed most to successful compensatory tracking. In our previous paper, we speculated that since rod density peaks at approximately 18-20^{o} off center, information presented to this general retinal area could result in optimal tracking. This study compares tracking abilities using equal line segments (line with a central gap) starting outside the foveal area (> $\pm$ 5^{o} from center) and extending to the extreme peripheral retina. The absolute length of the visual line is thus held constant while the position of the line is varied across the retina.

EXPERIMENT 1

SUBJECTS

Subjects were six Navy and Marine Corps flight candidates ranging in age from 21 to 26 years. All had recently passed a routine flight physical. One subject was left handed. Using his nondominant (right) hand, this subject had extremely poor tracking performance in all conditions and was not included in the data analysis.

APPARATUS

In order to produce an artificial horizon, a class 2 helium-neon laser (0.43 mW) was projected on a large (8 ft by 8 ft) rear-projection screen. The red laser beam was reflected by a set of servo-controlled, galvanometer-driven mirrors powered by two scanner amplifiers as shown in Fig. 1. The system produced an elongated artificial horizon that could be rotated to simulate roll motion. A random forcing function (Gaussian noise, bandwidth 0.15 Hz, amplitude 3.16 V rms) was used to induce roll of the projected horizon. The forcing voltage (3.16 V) produced a 30^{o} deflection of the horizon. The

lengths and configurations of the horizons were varied by inserting circular photographic film "masks" between the laser and the screen, occluding unwanted portions of the horizon.

BLOCK DIAGRAM OF PERIPHERAL VISION HORIZON DEVICE

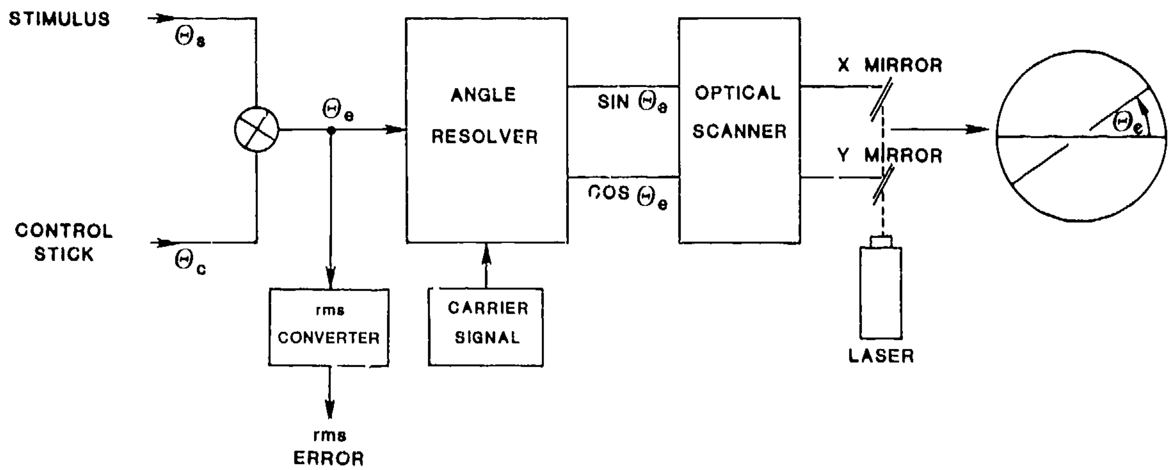

Figure 1. Complex tracking experimental configuration.

The subject was seated 1 m from the screen. The subject's chair was equipped with a headrest, and a displacement joystick was attached to the right armrest. A 30° deflection of the joystick produced a 30° deflection of the horizon. The forcing function and the signal from the joystick were fed to an A/D converter and a mini-computer to compute rms error.

METHOD

The subject was instructed to perform compensatory tracking (keep the horizon horizontal) using the joystick. The stimuli were six horizon configurations (Fig. 2) each with two horizon segments subtending 5° of visual angle, equally spaced to the right and left of visual center (5-10, 10-15, 15-20, 20-25, 30-35, 40-45°). During this experiment, subjects were required to visually focus on an imagined dot at the center of the laser horizon, which served as the axis for roll motion (x-axis rotation). The subjects were told that their ability to use peripheral vision was being tested and that they were not to look at the moving line segments. Adherence to this instruction was important, and the experimenter monitored compliance by careful observation.

Subjects were tested on 4 consecutive days, one session per day. Each session consisted of one 4-min trial using each horizon configuration with a 90-s rest between trials. A complete counterbalancing of the order of horizon presentations was not possible with the limited number of subjects available. Because we anticipated maximum performance with horizon lines at approximately 20° off-center, the order of presentation for the first three horizon sizes

(5-10, 10-15, and 15-20°) were completely counterbalanced. Half of the subjects received this set of horizons across their first three daily trials. The other subjects received the second set of horizons (20-25, 30-35, 40-45°) in a counterbalanced order across their first three daily trials. Daily trials four, five, and six included the remaining horizon sizes (counterbalanced order) for the respective subject populations.

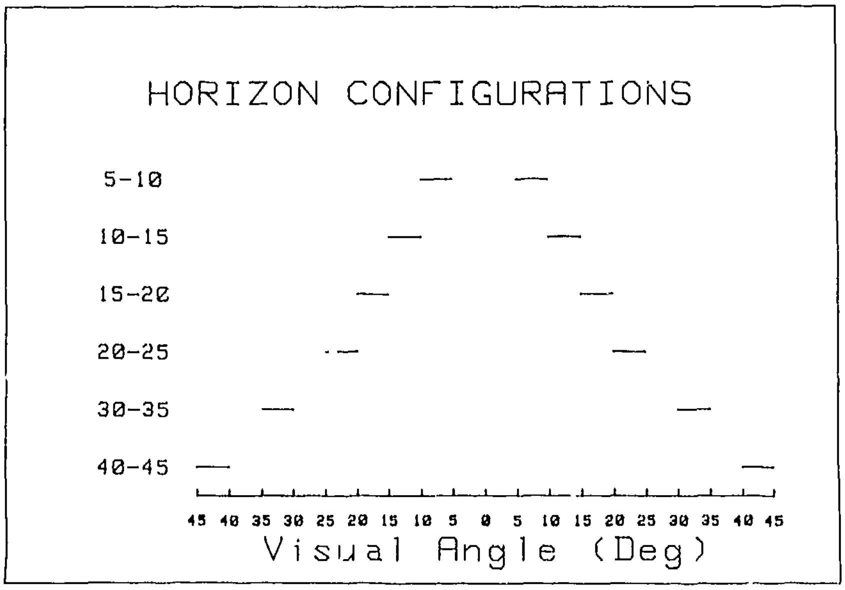

Figure 2. Artificial horizon configurations.

RESULTS

Tracking ability (Table 1) improved significantly across the 4 days (F (3, 27) = 10.20, $p < .001$), repeated measures ANOVA) as can be seen in Fig. 3. This figure also shows the significant horizon effect (F (5, 45) = 5.85, $p < .001$) with performance decreasing as the horizon line segments were moved further into peripheral vision.

Although the experimental design involved repeated measurements, interpretation of the results should be tempered due to the limited number of subjects observed (N = 5). Experiment 2 extended the number of subject observations and concentrated on the more visually narrow horizon sizes.

TABLE 1. Mean (SD) rms Tracking Error (V).

Horizon size (degree)	Testing day 1	2	3	4
5-10	589 (144)	517 (159)	480 (99)	477 (121)
10-15	566 (104)	506 (116)	513 (192)	478 (108)
15-20	594 (155)	550 (150)	568 (212)	497 (112)
20-25	634 (130)	557 (159)	497 (116)	548 (226)
30-35	621 (105)	567 (147)	552 (150)	507 (132)
40-45	766 (221)	624 (132)	595 (210)	620 (163)

EXPERIMENT 2

SUBJECTS

Subjects were 12 U.S. Army helicopter pilots ranging in age from 21 to 28 years. All subjects had recently passed a routine flight physical.

APPARATUS

The compensatory tracking task was identical to the preceding experiment with the exception that only three horizon configurations were used: $\pm (5\text{-}10)^{o}$, $\pm (10\text{-}15)^{o}$, and $\pm (15\text{-}20)^{o}$.

METHOD

Subjects were tested on 5 consecutive days, one session per day. The first 3 days were practice, and during the last 2 days, the subjects were tested under medicated (4 mg atropine I.M.) and nonmedicated (saline I.M.) conditions (counterbalanced order). Each session consisted of one 4-min trial for each horizon configuration with a 90-s rest between trials. The order of presentations was counterbalanced (two subjects for each of the possible orders), and each subject received the same presentation order on each of his 5 testing days.

RESULTS

Tracking ability (Table 2) was significantly better for the nonmedicated condition versus the atropine condition ($F(1, 11) = 26.05$, $p < .001$). We found no significant differences across horizon configurations.

TABLE 2. Mean (SD) rms Tracking Error (V) by Horizon Size.

Drug condition	Horizon configuration[a] 5-10°	10-15°	15-20°
Saline	521 (109)	502 (89)	534 (109)
Atropine	662 (172)	648 (136)	661 (186)

[a]See Fig. 2 for horizon configurations.

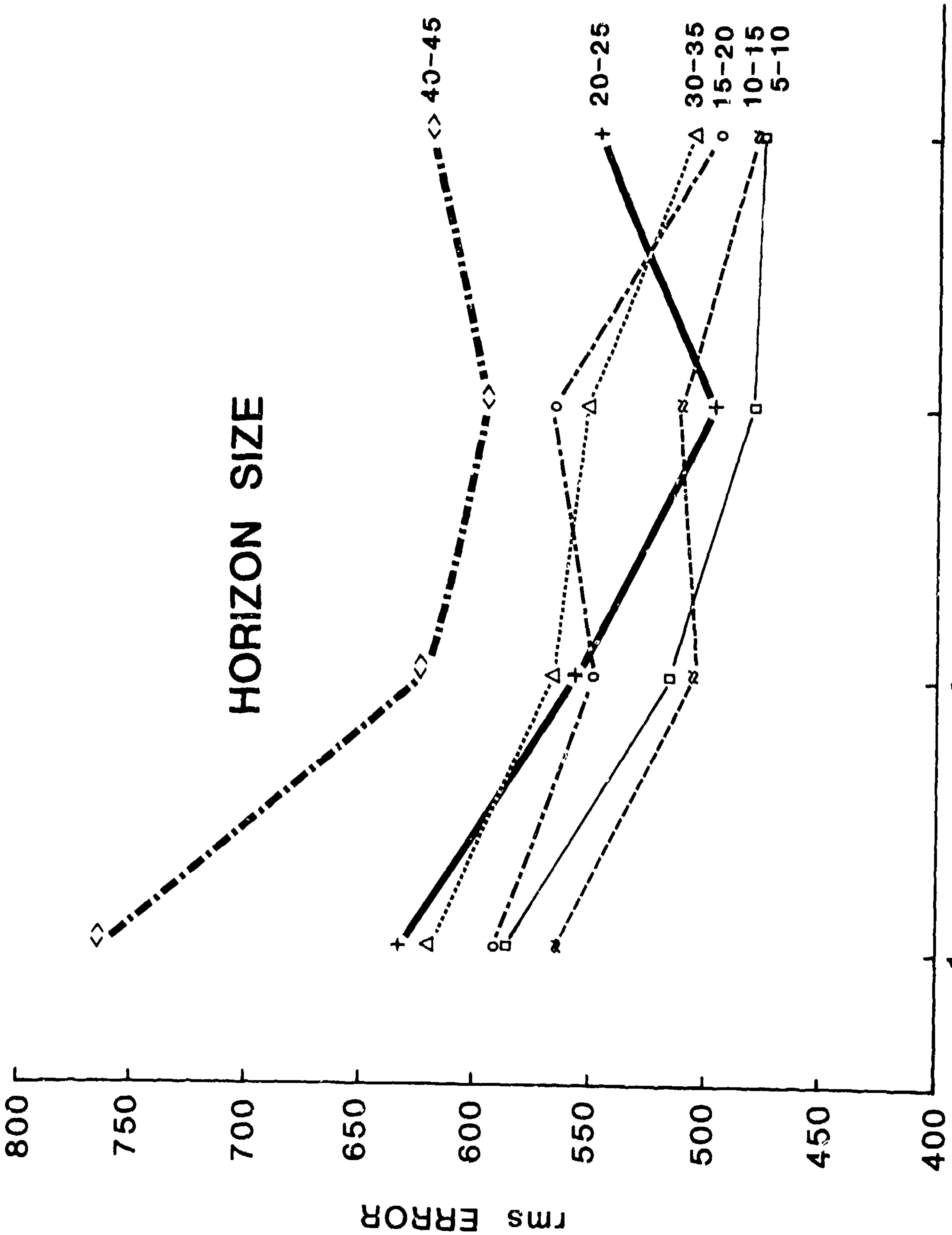

Figure 3. Root mean square tracking error.

DISCUSSION

The current set of experiments indicated that when horizon line segments were held equal in length, no advantage was gained by shifting the segments away from foveal vision (Experiment 1 & 2) and, in fact, tracking error increased as line segments were moved toward the periphery (Experiment 1). The hypothesis (7) that optimal tracking performance might be associated with stimuli presented to retinal areas having maximal rod density, approximately 18-20^{o} from the fovea, was not supported.

Experiment 2 was part of an investigation on chemical warfare antidote agents described in detail elsewhere (7). The significant difference (atropine vs. saline) in tracking abilities may have been the result of motor system impairment; and/or a loss of visual acuity. The lack of a significant difference between the three narrowest horizons (5-10, 10-15, and 15-20^{o} in Experiment 2 is difficult to explain in relation to results from Experiment 1. The most important point is that neither of the experiments suggested any advantage could be gained by moving constant sized horizon segments into peripheral vision.

Is the Peripheral Vision Horizon Device really a peripheral vision device per se? The best single-task tracking performance was obtained with centrally presented horizon lines. Tracking abilities improved somewhat as the horizon line was expanded to include peripheral vision (7). The PVHD may reduce instrument scan time by spatially reducing the distance required to shift between a traditional instrument and the projected horizon.

If further investigations find that the PVHD is not strictly a peripheral vision instrument but is being used as a giant attitude indicator, the device may still be an important addition to the cockpit. In terms of safe flight operations, attitude awareness may be the most important piece of flight data and making it foremost in the visual field should be advantageous. Disorientation accidents are costly in terms of loss of life and aircraft. A continued effort to find more effective ways to enhance attitude and situational awareness should be vigorously pursued.

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